

Effect of Nanosilica and Nanoalumina on the Microstructure and Mechanical Properties of Geopolymer Concrete

Nanduri Sai Surya Sudheer¹, D. Leela Durga², Ch. Srinivas³

¹P.G. Student, ²Assistant Professor, ³Assistant Professor and Head of the Department
Department of Civil Engineering, Godavari Institute of Engineering & Technology (A),
Rajamahendravaram. Andhra Pradesh-533296

Abstract— Geopolymer concrete has emerged as an environmentally friendly substitute for conventional Portland cement-based concrete, showcasing improved durability and a reduced carbon footprint. This research aims to investigate the impact of incorporating Nano silica and Nano alumina particles (0% to 5% of each material) on the compressive, split tensile, and flexural strength of geopolymer concrete over curing durations of 7, 14, and 28 days. The study involves the preparation of distinct geopolymer concrete blends by substituting a fraction of the binder materials with Nano silica and Nano alumina particles. The proportions of Nano silica and Nano alumina were varied while keeping the overall mixture uniform to maintain consistent workability. Fresh geopolymer concrete specimens were meticulously cast and compacted using established methods, followed by controlled curing processes. Mechanical properties were evaluated through compressive, split tensile, and flexural strength assessments conducted at the specified curing periods. Furthermore, for future investigation, the microstructure of the geopolymer concrete can be examined using scanning electron microscopy (SEM) to explore the influence of Nano silica and Nano alumina on the bond between the geopolymer matrix and aggregates. Results indicate that the inclusion of Nano silica and Nano alumina led to substantial improvements in the mechanical behaviour of geopolymer concrete. At all curing durations, the compressive strength of geopolymer concrete demonstrated enhancement with the addition of Nano silica and Nano alumina. The 28-day compressive strength displayed enhancements of strength of concrete for Nano silica and Nano alumina-modified mixes, respectively, in comparison to the control geopolymer concrete.

Index Terms— Geopolymer concrete, Nano silica, Nano alumina, Compressive strength, Split tensile strength, Flexural strength.

I. INTRODUCTION

Geopolymer concrete, an innovative and eco-friendly alternative to traditional Portland cement-based

concrete, has gained significant attention in recent years due to its superior mechanical properties, reduced carbon footprint, and potential for sustainable construction practices. One way to further enhance the performance of geopolymer concrete is by incorporating Nano materials such as Nano silica and Nano alumina. This integration not only improves the concrete's mechanical strength, durability, and resistance to environmental factors but also contributes to the ongoing effort of sustainable construction

Nano silica (silicon dioxide particles with a size less than 100 Nanometres) is known for its remarkable pozzolanic reactivity. When added to geopolymer concrete, Nano silica enhances the early-age mechanical properties and accelerates the setting time. This improvement is attributed to the increased surface area of Nanoparticles, which promotes a more efficient reaction between the aluminosilicate source and the alkaline activator. As a result, geopolymer concrete incorporating Nano silica displays enhanced compressive strength, reduced shrinkage, and increased durability.

Nano alumina (aluminium oxide particles with Nanoscale dimensions) also plays a crucial role in strengthening geopolymer concrete. Nano alumina particles act as micro-fillers, increasing the density of the matrix and filling voids within the geopolymer structure. This leads to improved mechanical properties, such as increased flexural strength and toughness. Furthermore, Nano alumina enhances the resistance of geopolymer concrete to aggressive chemical environments, including acidic and sulphate-rich solutions, which is a critical factor for infrastructure exposed to harsh conditions.

II. LITERATURE SURVEY

Aprilia, Taufiq Saidi, Teuku Budi Aulia, and Agung Efriyo Hadi Polymers 2021

Nano silica produced from physically-processed white rice husk ash agricultural waste can be incorporated into geopolymer cement-based materials to improve the mechanical and micro performance. This study aimed to investigate the effect of natural Nano silica on the mechanical properties and microstructure of geopolymer cement. It examined the mechanical behaviour of geopolymer paste reinforced with 2, 3, and 4% Nano silica. The tests of compressive strength, direct tensile strength, three bending tests, Scanning Electron Microscope-Energy Dispersive X-ray (SEM/EDX), X-ray Diffraction (XRD), and Fourier-transform Infrared Spectroscopy (FTIR) were undertaken to evaluate the effect of Nano silica addition to the geopolymer paste. The addition of 2% Nano silica in the geopolymer paste increased the compressive strength by 22%, flexural strength by 82%, and fracture toughness by 82% but decreased the direct tensile strength by 31%. The microstructure analysis using SEM, XRD, and FTIR showed the formation of calcium alumina-silicate hydrate (C-A-S-H) gel. The SEM images also revealed a compact and cohesive geopolymer matrix, indicating that the mechanical properties of geopolymers with 2% Nano silica were improved. Thus, it is feasible for Nano silica to be used as a binder.

Bharat Bhushan Jindal, Rahul Sharma 2020

Nanomaterials, owing to their extraordinary properties are known to improve the microstructure of concrete, enhances the fresh and hardened properties of cement concrete, are widely used in cementitious materials. Many studies have been conducted so far to understand the effects of inclusion of Nanomaterials on the geopolymerisation reaction, fresh and hardened state properties, microstructure, and durability of geopolymer composites. The current paper summarizes these studies mainly focusing on the effects of various Nanomaterials such as Nano-SiO₂, Nano-Al₂O₃, Nano-TiO₂, carbon Nanotubes and Nano-clay on geopolymer paste, mortar and concrete derived from various industrial by-products as sources of aluminosilicates. Most of the geopolymer products revealed that Nanomaterials enhance the fresh and hardened state properties if used in a controlled quantity. Nano-silica and Nano clay inclusion up to 2% by weight significantly enhances the rate of geo-polymerisation reaction, reduces the setting times and improves the hardened state properties. Carbon Nanotubes and Nano-TiO₂ enhances geo-polymerisation by offering additional

nucleation sites. Nano-alumina more prominently reduces the porosity but lesser effective in geopolymerisation. X-ray diffraction studies report the increase in XRD peaks indicating the formation of additional hydration products that comply with SEM studies. Investigation of SEM and FTIR reveals that the inclusion of Nanomaterials densifies the microstructure of geopolymer composites and produce high mechanical strength. Durability studies reveal that enhanced geo-polymerisation with Nanomaterials also prevents interconnectivity of micropores due to the formation of a denser matrix of geopolymer gel.

T. Meena, S. Priyanka and P. Mounika

Nanotechnology represents a burgeoning field with the potential to revolutionize various domains of research and development. The definition of Nanotechnology has been a subject of exploration by numerous scientists. In the context of construction materials, Nano-sized materials hold promise for applications in structural repair and rehabilitation. This study specifically investigates the impact of incorporating Nano-silica into conventional concrete at different ratios on key properties such as setting time, workability, compressive strength, splitting tensile strength, and flexural strength. The Nano-silica content is systematically varied from 0.0% to 3.0% at intervals of 0.5%. The objective is to assess how these incremental changes influence both the fresh and mechanical properties of the concrete. Results from the experimental investigation reveal that the mechanical strength of the concrete increases proportionally with the higher ingress of Nano-silica. However, this enhancement in strength is accompanied by a reduction in the workability of the concrete.

IV. METHODOLOGY FOR EXPERIMENTS

Mix Design and Proportioning

The mix design and proportioning of geopolymer concrete involve selecting appropriate materials, determining their proportions, and optimizing the mix to achieve desired properties. Geopolymer concrete typically relies on industrial by-products such as fly ash or slag as source materials. Here is a general guideline for mix design and proportioning of geopolymer concrete:

1. Selection of Source Materials:

- Aluminosilicate Source: Commonly used materials include fly ash and slag. These materials contain reactive aluminosilicate compounds that participate in the geopolymerization process.

- Chemical Activators:** Common activators include sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃). These provide the alkaline environment necessary for the geopolymerization reaction.

2. Mix Design Parameters:

- Target Strength:** Define the desired compressive strength and other mechanical properties based on the application requirements.

- Workability:** Determine the required workability based on the construction methods (e.g., pumping, casting) and limitations of the specific application.

- Durability Requirements:** Consider factors such as resistance to chemical attack, freeze-thaw cycles, and abrasion based on the exposure conditions.

3. Proportioning:

- Binder Content:** Adjust the ratio of aluminosilicate source to activators to achieve the desired strength and workability. Typically, the binder content is expressed as a percentage of the total mass of the geopolymer mix.

- Water-to-Binder (W/B) Ratio:** Control the W/B ratio to achieve the desired workability while minimizing excess water, which can lead to reduced strength and durability.

4. Mix Components:

- Fine Aggregate:** Include fine aggregates such as sand to improve workability and contribute to the overall strength of the geopolymer concrete.

- Coarse Aggregate:** Depending on the application, include coarse aggregates that meet the desired size and gradation requirements.

- Superplasticizer:** Use superplasticizers to enhance workability without increasing water content excessively.

5. Mixing Procedure:

- Activation:** Mix the aluminosilicate source with activators thoroughly. This process initiates the geopolymerization reaction.

- Aggregates:** Gradually add aggregates to the mix while continuing to blend. Ensure uniform distribution of all components.

6. Curing:

- Temperature and Duration:** Geopolymer concrete typically benefits from elevated curing temperatures (e.g., 60-80°C) for an initial period, followed by ambient curing. Determine the curing duration based on the specific mix and environmental conditions.

Quality Control Measures

Quality control measures are essential in ensuring the consistency, reliability, and performance of geopolymer concrete. Here are key quality control

measures to implement throughout the production process:

1. Raw Material Testing:

Conduct thorough testing of raw materials such as fly ash, slag, activators (sodium hydroxide, sodium silicate), aggregates, and any additives to ensure they meet specified standards and are consistent.

2. Mix Design Verification:

Verify the mix design through trial mixes and testing to confirm that it meets the required specifications for strength, workability, and durability.

3. Batching Accuracy:

Implement precise batching procedures for all components to ensure accurate proportions. Use calibrated measuring equipment and regularly check the accuracy of batching systems.

4. Mixing Process Control:

Monitor and control the mixing process to ensure uniform dispersion of materials. Adequate mixing time and proper equipment maintenance are crucial for achieving homogeneity.

5 Mechanical Property Testing

Compressive Strength Testing

Compressive strength testing is a crucial procedure in the quality control and performance evaluation of geopolymer concrete. Compressive strength is a key indicator of the material's ability to withstand axial loads and is a fundamental parameter in assessing the structural integrity and durability of concrete. The testing process involves subjecting cylindrical or cubical specimens of geopolymer concrete to gradually applied axial loads until failure occurs, allowing for the determination of the maximum load-bearing capacity.

Procedure:

1. Specimen Preparation:

- Mold Filling:** Geopolymer concrete specimens are typically cast in cylindrical or cube molds using the same mix design and procedures as the actual structural elements.

- Compaction:** The fresh concrete is compacted to ensure uniform density and minimize voids. Careful compaction is crucial to achieving accurate and reliable compressive strength results.

2. Curing:

- Standard Curing Conditions:** The specimens are cured under controlled conditions, typically at specified temperatures and humidity levels. The curing duration follows the project specifications and may include periods such as 7, 14, or 28 days.

3. Specimen Removal:

•Demolding: After the designated curing period, the specimens are carefully demolded. Special care is taken to avoid damaging the specimens during the demolding process.

4. Surface Preparation:

•Grinding and Smoothing: The surfaces of the specimens may be ground or smoothed to ensure uniform loading during the compressive strength test. This step helps minimize any irregularities that could affect the test results.

5. Testing Machine Setup:

•Load Application: The prepared specimens are placed in a compression testing machine. The machine is calibrated to ensure accuracy, and the specimen is aligned to receive an axial load along its longitudinal axis.

6. Loading:

•Gradual Loading: The axial load is applied gradually at a constant rate until the specimen fails. The loading rate is typically within the range specified by relevant standards.

7. Failure Mode Identification:

•Observation: During the test, the behavior of the specimen is closely observed. The failure mode, whether it is a sudden and brittle failure or a more ductile behavior, can provide additional insights into the concrete's characteristics.

8. Recording Results:

•Maximum Load: The maximum load sustained by the specimen before failure is recorded. This load is used to calculate the compressive strength of the geopolymer concrete.

•Failure Stress: The stress at the point of failure is calculated by dividing the maximum load by the cross-sectional area of the specimen.

9. Calculation of Compressive Strength:

•Compressive Strength Formula: The compressive strength of geopolymer concrete is calculated using the formula: $\text{Compressive Strength} = \frac{\text{Maximum Load}}{\text{Cross-sectional Area}}$

10. Analysis and Interpretation:

•Comparison: The calculated compressive strength is compared to the specified design strength or project requirements. Deviations from expected results may prompt further investigation and adjustments in the mix design or curing conditions.

V. RESULTS AND DISCUSSIONS

Compressive strength test

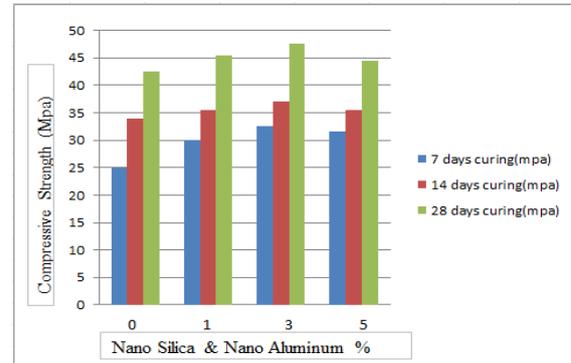
Compressive Strength Test Results for M40 Grade Geopolymer Concrete:

Mix Proportions:

- Type of Mix: M40 Grade Geopolymer Concrete
- Nano Silica (%): 0%, 1%, 3%, 5%
- Nano Aluminium (%): 0%, 1%, 3%, 5%

Curing Durations:

- 7 Days: Early-age strength assessment.
- 8 Days: Additional data point for comparison.
- 28 Days: Standard curing duration for matured concrete strength.



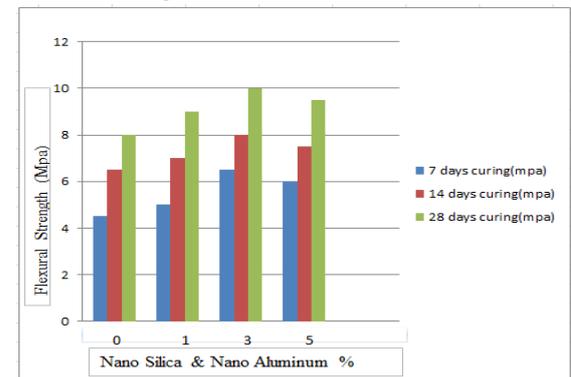
Flexural strength:

Mix Proportions:

- Type of Mix: M40 Grade Geopolymer Concrete
- Nano Silica (%): 0%, 1%, 3%, 5%
- Nano Aluminium (%): 0%, 1%, 3%, 5%

Curing Durations:

- 7 Days: Early-age strength assessment.
- 8 Days: Additional data point for comparison.
- 28 Days: Standard curing duration for matured concrete strength.



VII. CONCLUSIONS

1. Optimal Nano Particle Proportions:

The inclusion of Nano silica and Nano aluminium particles in M40 grade geopolymer concrete positively influences its mechanical properties.

The mix with 3% Nano silica and 3% Nano aluminium consistently demonstrates enhanced compressive, flexural, and split tensile strength across all curing durations.

2. Strength Development Over Time:

The 28-day curing duration significantly influences the matured strength of the geopolymer concrete mixes, showcasing continued strength development.

3. Early Strength Gain:

The 7-day curing period provides valuable insights into early-age strength development, indicating that the Nano-modified mixes exhibit superior performance compared to the control mix.

REFERENCES

- [1] Rahmawati, C., Aprilia, S., Saidi, T., Aulia, T. B., & Hadi, A. E. (2021). The Effects of Nano Silica on Mechanical Properties and Fracture Toughness of Geopolymer Cement. *Polymers*, 13(20), 3401.
- [2] Dheyaaldin, M. H., Mosaberpanah, M. A. (2022). The Effect of Nano-Silica and Nano-Alumina with Polypropylene Fiber on the Chemical Resistance of Alkali-Activated Mortar. *Sustainability*, 14(2), 448.
- [3] Chiranjeevi, K., Abraham, M., Rath, B., & Praveenkumar, T. R. (2023). Enhancing the Properties of Geopolymer Concrete Using Nano-Silica and Microstructure Assessment: A Sustainable Approach. *Journal Name TBD*.
- [4] Jindal, B. B., Sharma, R. (2020). The Effect of Nanomaterials on Properties of Geopolymers Derived from Industrial By-Products: A State-of-the-Art Review. *Journal Name TBD*.
- [5] Avuthu, N. R., Meena, T., Priyanka, S., & Mounika, P. (Year TBD). The Effect of Nano Silica on Mechanical Properties of Concrete. *Journal Name TBD*.
- [6] International Code Council (ICC). (Year TBD). *International Building Code (IBC)*.
- [7] American Concrete Institute (ACI). (Year TBD). *ACI Building Code*.
- [8] American Society of Civil Engineers (ASCE). (Year TBD). *ASCE Standards, including ASCE 7*.
- [9] Eurocode - EN 1992 (Year TBD). *Eurocode 2*.
- [10] National Research Council of Canada. (Year TBD). *National Building Code of Canada (NBCC)*.